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THRUST PAD ASSEMBLY FOR ECP SYSTEM

Field of the Invention

[001] The present invention relates to electrochemical plating systems used in the deposition of metal layers on semiconductor wafer substrates in the fabrication of semiconductor integrated circuits. More particularly, the present invention relates to an electrochemical plating system having a thrust pad assembly which reduces the quantity of metal electroplated on the edge regions of a cathode/wafer by the application of variable pressure to the center and edge regions of the wafer.

Background of the Invention

[002] In the fabrication of semiconductor integrated circuits, metal conductor lines are used to interconnect the multiple components in device circuits on a semiconductor wafer. A general process used in the deposition of metal conductor line patterns on semiconductor wafers includes deposition of a conducting layer on the silicon wafer substrate; formation of a photoresist or other mask such as titanium oxide or silicon oxide, in the form of the desired metal conductor line pattern, using standard lithographic techniques; subjecting the wafer substrate to a dry etching process to remove the conducting

layer from the areas not covered by the mask, thereby leaving the metal layer in the form of the masked conductor line pattern; and removing the mask layer typically using reactive plasma and chlorine gas, thereby exposing the top surface of the metal conductor lines. Typically, multiple alternating layers of electrically conductive and insulative materials are sequentially deposited on the wafer substrate, and conductive layers at different levels on the wafer may be electrically connected to each other by etching vias, or openings, in the insulative layers and filling the vias using aluminum, tungsten or other metal to establish electrical connection between the conductive layers.

[003] Deposition of conductive layers on the wafer substrate can be carried out using any of a variety of techniques. These include oxidation, LPCVD (low-pressure chemical vapor deposition), APCVD (atmospheric-pressure chemical vapor deposition), and PECVD (plasma-enhanced chemical vapor deposition). In general, chemical vapor deposition involves reacting vapor-phase chemicals that contain the required deposition constituents with each other to form a nonvolatile film on the wafer substrate. Chemical vapor deposition is the most widely-used method of depositing films on wafer substrates in the fabrication of integrated circuits on the substrates.

[004] Due to the ever-decreasing size of semiconductor components and the ever-increasing density of integrated circuits on a wafer, the complexity of interconnecting the components in the circuits requires that the fabrication processes used to define the metal conductor line interconnect patterns be subjected to precise dimensional control. Advances in lithography and masking techniques and dry etching processes, such as RIE (Reactive Ion Etching) and other plasma etching processes, allow production of conducting patterns with widths and spacings in the submicron range. Electrodeposition or electroplating of metals on wafer substrates has recently been identified as a promising technique for depositing conductive layers on the substrates in the manufacture of integrated circuits and flat panel displays. Such electrodeposition processes have been used to achieve deposition of the copper or other metal layer with a smooth, level or uniform top surface. Consequently, much effort is currently focused on the design of electroplating hardware and chemistry to achieve high-quality films or layers which are uniform across the entire surface of the substrates and which are capable of filling or conforming to very small device features. Copper has been found to be particularly advantageous as an electroplating metal.

[005] Electroplated copper provides several advantages over electroplated aluminum when used in integrated circuit (IC) applications. Copper is less electrically resistive than aluminum and is thus capable of higher frequencies of operation. Furthermore, copper is more resistant to electromigration (EM) than is aluminum. This provides an overall enhancement in the reliability of semiconductor devices because circuits which have higher current densities and/or lower resistance to EM have a tendency to develop voids or open circuits in their metallic interconnects. These voids or open circuits may cause device failure or burn-in.

[006] Fig. 1 schematically illustrates a typical standard or conventional electroplating system 10 for depositing a metal such as copper onto a semiconductor wafer 18. The electroplating system 10 includes a standard electroplating cell having an adjustable current source 12, a bath container 14, a copper anode 16 and a cathode 18, which cathode 18 is the semiconductor wafer that is to be electroplated with copper. The anode 16 and the semiconductor wafer/cathode 18 are connected to the current source 12 by means of suitable wiring 38. The bath container 14 holds a bath 20 typically of acid copper sulfate solution which may include an additive for

filling of submicron features and leveling the surface of the copper electroplated on the wafer 18.

[007] In operation of the electroplating system 10, the current source 12 applies a selected voltage potential typically at room temperature between the anode 16 and the cathode/wafer 18. This potential creates a magnetic field around the anode 16 and the cathode/wafer 18, which magnetic field affects the distribution of the copper ions in the bath 20. In a typical copper electroplating application, a voltage potential of about 2 volts may be applied for about 2 minutes, and a current of about 4.5 amps flows between the anode 16 and the cathode/wafer 18. Consequently, copper is oxidized typically at the oxidizing surface 22 of the anode 16 as electrons from the copper anode 16 and reduce the ionic copper in the copper sulfate solution bath 20 to form a copper electroplate (not illustrated) at the interface between the cathode/wafer 18 and the copper sulfate bath 20.

[008] The copper oxidation reaction which takes place at the oxidizing surface 22 of the anode 16 is illustrated by the following reaction formula (1):

$$(1) \quad Cu \text{ ----> } Cu^{++} + 2e^{-}$$

[009] The oxidized copper cation reaction product forms ionic copper sulfate in solution with the sulfate anion in the bath 20:

$$(2) \quad Cu^{++} + SO_4^{--} \text{----}> Cu^{++}SO_4^{--}$$

[0010] At the cathode/wafer 18, the electrons harvested from the anode 16 flow through the wiring 38 and reduce copper cations in solution in the copper sulfate bath 20 to electroplate the reduced copper onto the patterned surface 19a of the cathode/wafer 18:

$$(3) \quad Cu^{++} + 2e^{-} \text{----}> Cu$$

[0011] As the anode 16 is consumed during the electroplating process, small quantities of solid copper sulfate or "anode fines" tend to precipitate at the interface between the copper sulfate bath 20 and the oxidizing surface 22 of the anode 16 to form a copper precipitate or sludge on the oxidizing surface 22.

[0012] As shown in FIG. 2, during the electroplating process air pressure 26 is applied against a thrust pad 24, which in turn applies pressure through a contact ring (not shown) that is disposed in electrical contact with the current source 12 and

presses against the backside 19 of the cathode/wafer 18. The pressure exerted by the contact ring against the backside 19 of the cathode/wafer 18 increases the ohmic contact between the contact ring and the cathode/wafer 18, thus enhancing electroplating of the copper or other metal on the patterned surface 19a of the cathode/wafer 18. The air pressure 26 is typically the same throughout all regions on the entire surface of the thrust pad 24. Accordingly, substantially equal quantities of the electroplated copper are applied to both the center region 18a and the edge regions 18b of the cathode/wafer 18.

[0013] After the electroplating process, some excess electroplated metal must typically be removed from the edge regions 18b of the cathode/wafer 18 since excess metal in the edge regions 18b is potentially a significant source of contaminant particles during subsequent processing of the wafer 18. This excess metal removal process is typically carried out using an edge bevel clean process that is integrated into the electrochemical plating apparatus. However, such edge bevel cleaning of wafers required after electroplating is a common source of process flow bottlenecking and hinders orderly and efficient flow of the electroplating process sequence.

[0014] It has been found that the quantity of metal electroplated onto the edge region of a substrate can be reduced by the application of reduced-magnitude pressure to the edge region of the substrate during electrochemical plating, thus reducing the ohmic contact between the contact ring and the edge region of the substrate. This eliminates the need for edge bevel cleaning of substrates after electrochemical plating and facilitates efficient and orderly flow of substrates and increases throughput of electrochemically-plated substrates throughout a process flow sequence during the fabrication of semiconductor integrated circuits.

[0015] Accordingly, an object of the present invention is to provide a new and improved thrust pad assembly which can be adapted to an electrochemical plating system.

[0016] Another object of the present invention is to provide a new and improved thrust pad which is capable of applying pressure of reduced magnitude against the edge region of a substrate to reduce or eliminate the deposition of excess quantities of a metal on the edge region during electrochemical plating of the substrate.

[0017] Still another object of the present invention is to provide a new and improved thrust pad assembly which generates zones of variable pressure against a substrate in the electrochemical plating of the substrate.

[0018] Yet another object of the present invention is to provide a new and improved thrust pad assembly which is capable of reducing or eliminating the need for edge bevel cleaning of substrates after electrochemical plating.

[0019] A still further object of the present invention is to provide a new and improved thrust pad assembly which significantly increases throughput of substrates during electrochemical plating.

[0020] Another object of the present invention is to provide a novel method for electroplating a metal onto a substrate.

Summary of the Invention

[0021] In accordance with these and other objects and advantages, the present invention is generally directed to a new and improved thrust pad assembly which is capable of reducing the quantity of metal electroplated onto the edge region of a

substrate to eliminate or reduce the need for edge bevel cleaning or removal of excess metal from the substrate after the electroplating process. The thrust pad assembly typically includes an air platen through which air is applied at variable pressures to the central and edge regions, respectively, of a thrust pad. The thrust pad applies pressure to a contact ring connected to an electroplating voltage source. The contact ring applies relatively less pressure to the edge region than to the central region of the substrate, thereby reducing the ohmic contact between the contact ring and the edge region of the substrate. Therefore, excess electroplating of the metal onto the edge regions of the substrate is eliminated or substantially reduced.

[0022] The present invention further includes a method of electroplating a metal on a substrate. The method includes providing a substrate, providing a contact ring in contact with the substrate, providing the contact ring and the substrate in an electrolyte bath, providing an anode in the electrolyte bath, applying a voltage to the contact ring and the anode, applying a central pressure to a central region on the substrate, and applying a peripheral pressure which is less than the central pressure to an edge region on the substrate.

Brief Description of the Drawings

[0023] The invention will now be described, by way of example, with reference to the accompanying drawings, in which:

[0024] FIG. 1 is a schematic view of a typical conventional electrochemical plating system for the electrochemical plating of a metal layer onto a substrate;

[0025] FIG. 2 is a schematic view of a typical conventional thrust pad assembly for an electrochemical plating system;

[0026] FIG. 3 is a cross-sectional, partially schematic, view of a thrust pad assembly in accordance with the present invention;

[0027] FIG. 4 is a schematic view of an electrochemical plating system in implementation of the thrust pad assembly of the present invention;

[0028] FIG. 5 is a top view of an air platen element in an illustrative embodiment of the thrust pad assembly of the present invention; and

[0029] FIG. 6 is a graph illustrating the relationship between plating thickness (on the Y-axis) and pressure (on the X-axis) applied by the thrust pad assembly of the present invention.

Description of the Preferred Embodiments

[0030] The present invention has particularly beneficial utility in the electroplating of copper or other metals onto a semiconductor wafer substrate in the fabrication of integrated circuits on the substrate. However, the invention is not so limited in application, and while references may be made to such semiconductor wafer substrate and integrated circuits, the invention may be more generally applicable to electroplating metals on substrates in a variety of industrial applications.

[0031] The present invention is generally directed to a new and improved thrust pad assembly which is suitable for preventing deposition of excess quantities of metal onto the edge or peripheral region of a substrate as copper or other metal is electroplated onto the substrate in the fabrication of semiconductor integrated circuits on the substrate. The thrust pad assembly eliminates the need for edge bevel cleaning or removal of excess metal from the edge region of the substrate

after the electroplating process. The thrust pad assembly typically includes an air platen through which air is applied at variable pressures to the central and edge regions, respectively, of a thrust pad. The thrust pad, in turn, transmits this variable pressure to a contact ring which is electrically connected to the electroplating current source. The thrust pad applies relatively less pressure to the edge region than to the central region of the substrate, thus reducing ohmic contact between the contact ring and the edge region of the substrate. Electrical resistance between the anode and the edge region of the substrate is reduced with respect to the electrical resistance between the anode and the central region of the substrate. This variable pressure application to the substrate, and resulting disparity in electrical resistance, is used to control the substrate plating shape such that excess electroplating of the metal onto the edge region of the substrate is reduced or eliminated while electroplating of the metal onto the central region of the substrate remains optimal.

[0032] The present invention further contemplates a method of electroplating a metal on a substrate. The method includes providing a substrate, providing a contact ring in contact with the substrate, immersing the contact ring and the substrate in

an electrolyte bath, immersing an anode in the electrolyte bath, applying a voltage to the contact ring and the anode, applying a central pressure to a central region on the substrate, and applying a peripheral pressure which is less than the central pressure to an edge region on the substrate.

[0033] Referring to FIGS. 3-5, an illustrative embodiment of the thrust pad assembly of the present invention is generally indicated by reference numeral 40. The thrust pad assembly 40 includes a generally disk-shaped air platen 42 having a circular central region 42a and an annular edge region 42b surrounding the central region 42a, as shown in FIG. 5. In a typical embodiment, the central region 42a represents typically from about 50% to about 80% of the total surface area of the air platen 42, whereas the encircling edge region 42b represents typically from about 20% to about 50% of the total surface area of the air platen 42. Multiple central air openings 44 extend through the central region 42a of the air platen 42, and multiple peripheral air openings 46 extend through the edge region 42b of the air platen 42. As shown in FIG. 3, the central air openings 44 are provided in pneumatic communication with a central air source 76 of central air pressure 45, and the peripheral air openings 46 are provided in pneumatic

communication with a peripheral air source 77 of peripheral air pressure 47.

[0034] As further shown in FIG. 3, an electrically-conductive contact ring 50 extends downwardly from the bottom surface of the air platen 42, and a thrust pad 48 is provided in the contact ring 50. The thrust pad 48 is typically a resilient material such as rubber. As shown in FIG. 3, the central air openings 44 and the peripheral air openings 46 of the air platen 42 communicate with the upper surface 49 of the thrust pad 48. A wafer clamp 52 (shown in phantom) removably secures a cathode/wafer 54 to the bottom surface of the contact ring 50, typically in conventional fashion.

[0035] Referring to FIG. 4, a schematic of an electroplating system 60 which is suitable for implementation of the present invention is shown. The electroplating system 60 typically includes a bath container 64 in which a typically copper anode 66 and the thrust pad assembly 40 to which is mounted the cathode/wafer 54 are placed, the cathode/wafer 54 being the semiconductor wafer that is to be electroplated with the copper or other metal. A negative terminal 62a of an adjustable current source 62 is connected to the contact ring 50 of the thrust pad assembly 40 through wiring 67. A positive terminal

62b of the adjustable current source 62 is connected to the anode 66 through wiring 68. The bath container 64 holds an electroplating bath 70 typically of acid copper sulfate ($CuSO_4$) solution, for example, which may include an additive for filling of submicron features and leveling the surface of the copper electroplated on the wafer 54, as is known by those skilled in the art. The electroplating system 60 may include additional features such as a bypass pump/filter (not shown) connected to the bath container 64 and an electrolyte holding tank (not shown) connected to the the bypass pump/filter and to the bath container 64 to facilitate the addition of electrolytes to the bath 70 and circulation of the bath 70, as needed.

[0036] Referring next to Figures 3 and 4, in application of the thrust pad assembly 40, the thrust pad assembly 40 is initially assembled in the bath container 64, with the clamp 52 (FIG. 3) attaching the wafer 54 to the contact ring 50, and the anode 66 and the thrust pad assembly 40 with the cathode/wafer 66 are immersed in the electrolyte bath 70. The electroplating system 60 is operated typically in conventional fashion to electroplate the metal from the metal electrolyte solution in the bath 70, onto the patterned surface 57a of the wafer 54. Accordingly, the current source 62 applies a selected voltage potential, typically at room temperature, between the anode 66

and the cathode/wafer 54. This voltage potential creates a magnetic field around the anode 66 and the cathode/wafer 54, which magnetic field affects the distribution of the metal ions in the electrolyte bath 70. In a typical copper electroplating application, a voltage potential of about 2 volts may be applied for about 2 minutes, and a current of about 4.5 amps flows between the anode 66 and the cathode/wafer 54. Consequently, the metal is oxidized typically at the upper oxidizing surface of the anode 66 as electrons from the metal anode 66 reduce the ionic metal in the electrolyte solution bath 70 to form a substantially corrosion-resistant electroplated metal layer 74 on the patterned surface 57a of the wafer 54, as shown in FIG. 4, at the interface between the cathode/wafer 54 and the electrolyte bath 70.

[0037] As the metal layer 74 is electroplated onto the wafer 54, the contact ring 50 of the thrust pad assembly 40 applies pressure of variable magnitude against the backside 57 of the wafer 54, as follows. As shown in FIG. 3, central air pressure 45 is directed from the central air source 76 through the respective central air openings 44 of the air platen 42 and against the upper surface 49 of the thrust pad 48 at a pressure of typically greater than about 14 psi. Similarly, peripheral air pressure 47 is directed from the peripheral air source 77

through the respective peripheral air openings 46 of the air platen 42 and against the upper surface 49 of the thrust pad 48 at a pressure of typically less than about 14 psi. Accordingly, the central portion of the contact ring 50 applies a pressure of typically greater than about 14 psi to the backside 57 of the wafer 54, whereas the peripheral portion of the contact ring 50 applies a pressure of typically less than about 14 psi to the backside 57 of the wafer 54. Because the ohmic contact between the contact ring 50 and the wafer 54 is directly proportional to the pressure applied by the contact ring 50 against the wafer backside 57, the electrical resistance between the anode 66 and the cathode/wafer 54 at the edge region 54b of the wafer 54 is correspondingly less than the electrical resistance between the anode 66 and the cathode/wafer 54 at the center region 54a of the wafer 54. Consequently, the electroplated metal 57a is correspondingly thicker at the center region 54a than at the edge region 54b of the wafer 54 for a given period of electroplating time. Typically, the electroplating process is carried out for a period of typically about 2 minutes to deposit an electroplated metal 74 having a thickness of typically at least about 7,000 angstroms at the center region 54a and a thickness of typically about 500- 1000 angstroms at the edge region 54b of the wafer 54.

[0038] It will be appreciated by those skilled in the art that because the thickness of the electroplated metal 74 at the edge region 54b of the wafer 54 is attenuated with respect to the thickness of the electroplated metal 74 at the center region 54a throughout the electroplating process, electroplating of excessive quantities of the metal layer 74 at the edge region 54b of the wafer 54 is prevented. Accordingly, there is no need to subject the wafer 54 to edge bevel clean methods which would otherwise be needed to remove excess electroplated metal from the edge region 54b. This eliminates process bottlenecking at the electroplating station and promotes an orderly and efficient flow of wafers through the electroplating process.

[0039] Referring next to the graph of FIG. 6, wherein the relationship of pressure applied against the backside of a wafer is shown in relation to the thickness of metal electroplated onto the wafer. As indicated by reference numeral 50, when a pressure of from about 0 psi to about 13 psi is applied to the backside of the wafer, the thickness of metal electropated onto the wafer is from typically about 100 to about 500 angstroms. When a pressure of greater than about 14 psi is applied to the backside of the wafer, the thickness of metal electroplated onto the wafer is about 7,000 angstroms. As indicated by reference

numeral 60, this thickness gradually increases at pressures above about 23 psi.

[0040] While the preferred embodiments of the invention have been described above, it will be recognized and understood that various modifications can be made in the invention and the appended claims are intended to cover all such modifications which may fall within the spirit and scope of the invention.